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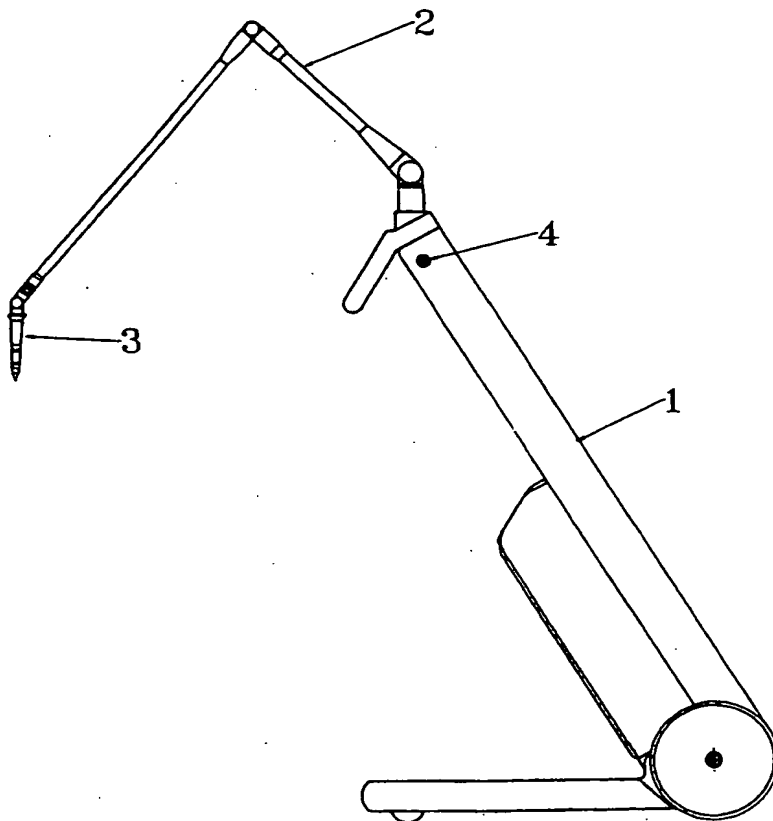
## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(71) Applicant (for all designated States except US): MEDICAL LASER TECHNOLOGIES LIMITED [GB/GB]; Unit 4, Belleknowes Industrial Estate, Inverkeithing, Fife KY11 1HY (GB).		<b>Published</b> With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.	
(72) Inventor; and (75) Inventor/Applicant (for US only): COLLES, Michael, John [GB/GB]; Boglesknowe, Hartree By Biggar, Lanarkshire ML12 6TG (GB).			
(74) Agent: MURGITROYD & COMPANY; 373 Scotland Street, Glasgow G5 8QA (GB).			

(54) Title: LASER SYSTEM

## (57) Abstract

The invention relates to the application of lasers for controlled ablation of tissue, particularly but not solely for use in dentistry. The invention provides a CO<sub>2</sub> laser system comprising laser head, control means and scanning means wherein a laser beam is delivered in organised bursts of pulses to the tissue to be ablated.



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1     Laser System

2

3     The present invention relates to the application of  
4     lasers for the controlled ablation of tissue. More  
5     particularly the invention relates to the application  
6     of lasers in dentistry.

7

8     In this field it is known that certain lasers can be  
9     used to drill through hard biological tissue such as  
10    bone and the tooth enamel and dentine of teeth. In  
11    particular the Erbium:YAG laser operating at a  
12    wavelength of 2.94  $\mu\text{m}$ , a wavelength that is especially  
13    strongly absorbed by water bearing tissue, has  
14    demonstrated efficient drilling without substantial  
15    damage to surrounding tissue when used in conjunction  
16    with a water spray. Such systems are now becoming  
17    available commercially. Short wavelength (0.19 $\mu\text{m}$ )  
18    Excimer lasers show a similar ability to provide clean  
19    cuts in tooth and bone tissue. These lasers provide  
20    relatively high energy pulses at a low repetition rate.  
21    Carbon dioxide lasers configured to operate in a  
22    similar way, that is with high energy short pulses  
23    (<10 $\mu\text{s}$ ) at a low rate have also been reported to offer  
24    reasonably clean drilling although it is perceived that  
25    less strong water absorption at their wavelength of

1 10.6 $\mu$ m renders them less effective. It has been  
2 demonstrated that the far more common continuous wave  
3 (cw) or so-called "superpulse" CO<sub>2</sub> lasers overheat teeth  
4 with both undesirable carbon formation and potential  
5 damage to any underlying vital pulp.  
6

7 These approaches have a number of disadvantages in  
8 terms of their application to dentistry. In  
9 particular the Excimer lasers are large and expensive  
10 requiring careful chemical engineering in the handling  
11 of their toxic gas constituents. This makes them  
12 entirely inappropriate for typical dental  
13 installations. Similarly the short pulse high energy  
14 CO<sub>2</sub> lasers, whilst common in industrial settings have no  
15 history of use in medical applications. The  
16 Erbium:YAG laser clearly can drill teeth effectively  
17 although it also is a relatively expensive system in  
18 the context of a typical dental installation.  
19

20 The present invention aims to provide a method of  
21 drilling teeth with lasers which overcomes the  
22 aforementioned problems of the prior art.  
23

24 According to the present invention there is provided a  
25 CO<sub>2</sub> laser system for ablation of tissue comprising a  
26 laser head, and control means whereby a focused laser  
27 beam is produced in organised bursts of pulses from the  
28 laser head to an area of tissue to be ablated.  
29

30 Preferably the system further provides scanning means  
31 by which the focused beam traverses a defined area such  
32 as an area of tissue to be ablated.  
33

34 Also according to the invention there is provided a  
35 method for the controlled ablation of tissue comprising  
36 the steps of delivering a focused laser beam from a CO<sub>2</sub>

1 laser in organised bursts of pulses to the tissue to be  
2 ablated.

3

4 Preferably the method further comprises the step  
5 whereby the focused laser beam scans the area to be  
6 ablated.

7

8 Preferably the wavelength ( $\lambda$ ) of the laser pulses is  
9 between 9 and  $11\mu\text{m}$ .

10

11 Preferably pulse duration may be between  $100\text{-}700\mu\text{s}$ .

12

13 Preferably between 1 and 10 pulses form a burst and  
14 pulses in a burst may be separated by between 200 and  
15  $1000\mu\text{sec}$ . More preferably pulse separation is between  
16 25 and  $600\mu\text{s}$  and most preferably  $250\text{-}350\mu\text{s}$ .

17

18 Preferably burst repeat frequency may be between 10 and  
19  $100\text{Hz}$ .

20

21 More preferably burst frequency is between  $30\text{-}50\text{ Hz}$ .

22

23 Preferably 10 to  $50\text{mJ}$  of pulse energy is delivered in a  
24 beam focused to a diameter of typically  $300\mu\text{m}$ .

25

26 As described herein the invention provides a method  
27 whereby effective drilling of all types of tooth tissue  
28 can be achieved with the output beam from suitably  
29 modified  $\text{CO}_2$  lasers typical of those used commonly in  
30 medical applications.

31

32 To achieve clean drilling without either damage to  
33 adjacent tissue or subsequent cracking of enamel and  
34 dentine requires a specific organisation of the output  
35 into groups of pulses as described below. It is this  
36 specific grouping of pulses together with their

1 duration and profile which constitutes the successful  
2 activity of this invention. The relatively low energy  
3 pulses from such quasi-cw lasers can still produce  
4 efficient explosive ablation provided that the beam is  
5 focused down to a spot size of sufficiently small size.  
6 The invention may further provide a scanning means by  
7 which a small spot can traverse in an automatic preset  
8 fashion a pattern that gives the size of the drill hole  
9 characteristically required in dentistry. The timing  
10 of the grouped laser pulses on the scanned spot is  
11 achieved in such a way that a simple drilling action is  
12 perceived. This combination of specific arrangements  
13 of pulses in an output beam that is tightly focused and  
14 scanned provides a novel and non-obvious route to laser  
15 drilling of teeth using CO<sub>2</sub> lasers. The process as  
16 with current Er:YAG systems or standard mechanical  
17 drills requires the simultaneous presence of a fine  
18 water spray to assist in cooling.

19  
20 Specifically it can be demonstrated that the following  
21 of features lead to the beneficial removal of dental  
22 hard tissue:

- 23
- 24 1. Pulsing of the laser for significantly lower  
25 durations than in the established "superpulse"  
26 mode.
  - 27
  - 28 2. Limiting the output to a burst of such pulses  
29 relatively few in number.
  - 30
  - 31 3. Providing a long enough gap between such bursts  
32 such that their advantageous characteristics are  
33 not affected.
  - 34
  - 35 4. Ensuring a strong interaction by tightly focusing  
36 the high quality beam onto the tissue.

1     5.     Ensuring that the surfaces are maintained wet to  
2             further enhance the interaction and provide  
3             additional cooling.

4  
5     In support of these individual aspects it can be argued  
6     that reducing the laser pulse duration to, for example  
7     200 $\mu$ s enhances the relative contribution of the  
8     initiating spike to the overall pulse energy. The  
9     contribution from this spike is in any case greater in  
10    the first few pulses from an initial turn on due to the  
11    lack of ionised particles in the laser gas and the  
12    consequent need for more energy to initiate the  
13    discharge. By limiting the number of pulses delivered  
14    to a low number within a burst and further limiting the  
15    burst frequency such that each can be regarded as  
16    seeing an electrically cold gas, such an enhancement of  
17    the pulse power can be maintained. The level of  
18    enhancement depends on the position of a pulse within a  
19    burst; the first carrying a significant proportion of  
20    its energy within the short initiating spike (a few  $\mu$ s  
21    duration) and thus peak powers typically in excess of  
22    200 watts, (in a laser giving around 20 watts when used  
23    cw), whilst subsequent pulses typically carry an  
24    increasing, but more uniformly distributed, energy.  
25    Overall the average power enhancement factor is  
26    typically x5 compared with the normal superpulse mode  
27    enhancement of x2.

28  
29    The initial spike provides the high power which makes  
30    this mode of operation similar in its effectiveness on  
31    hard tissue to the previously mentioned purely pulsed  
32    CO<sub>2</sub> systems having durations of less than 10 $\mu$ s. Having  
33    initiated the interaction on tissue subsequent pulses  
34    within the burst provides the energy needed to remove  
35    significant volumes of material. In order to provide  
36    an effective drilling the burst must be repeated at a

1 sufficiently high rate to give significant material  
2 removal. This must be balanced by both the  
3 requirements of maintaining the characteristics of an  
4 individual burst and allowing the tissue immediately  
5 adjacent to the ablated region to cool.  
6

7 The requirement for the successful ablation of any  
8 tissue is to supply efficient energy at a high enough  
9 rate to ensure removal of the affected zone before  
10 conduction processes have led to any potentially  
11 damaging heating of the surrounding area. This is  
12 achieved in dental hard tissues by using very high  
13 power densities, typically  $50\text{ kW/cm}^2$ . In the case of  
14 our example here of a relatively low power cw  
15 equivalent laser this implies focusing to small spot  
16 size of around  $0.3\text{ mm}$  diameter. The appearance of a  
17 larger drill hole, as required to match conventional  
18 dental practice, together with further interpulse  
19 cooling of a given interaction volume is achieved by  
20 scanning the beam in for example a circular fashion  
21 such that an overall diameter of around  $1\text{ mm}$  is  
22 achieved. The gap between subsequent pulses over the  
23 same position is consequently increased to 4 times the  
24 interpulse spacing. (Such scanning is materially  
25 different to that introduced by US Patent 5411502  
26 wherein the interaction mechanism itself is  
27 specifically controlled by the rapid scanning of a cw  
28 beam. The scanning referred to in the present  
29 invention has no effect on the interactive mechanism  
30 which results from the nature of the pulse sequences  
31 and the tightly focussed beam).  
32

33 The water content of both enamel and dentine is  
34 significantly less than that of soft tissue. The  
35 water spray enhances the surface water in the region of  
36 the impact area and thus assists the absorption of the



1 laser energy. It also provides an additional and  
2 important heat sink which is effective in ensuring both  
3 virtually no cracking to the surrounding enamel and no  
4 significant temperature rise within the underlying  
5 tissue.

6

7 A CO<sub>2</sub> laser set to operate within this combination of  
8 parameters defined herein satisfactorily drills enamel  
9 and dentine without cracking or pulpal heating.  
10 Experimentally this has been demonstrated by varying  
11 the pulse duration  $T_p$ , the gap between pulses in a  
12 burst  $T_g$ , the number of pulses in a burst  $N_b$  and the  
13 burst repetition frequency to identify an optimum  
14 combination of parameters for both enamel and dentine.  
15 Whilst an optimum set can be identified an effective  
16 and safe interaction can be achieved over a reasonable  
17 range of each individual parameter. For example  
18 enamel is best addressed with a lower  $N_b$  and shorter  
19  $T_p$ . Softer material such as carious dentine is less  
20 demanding and can tolerate more and longer pulses in  
21 each burst.

22

23 This has been determined that pulse durations ( $T_p$ ) from  
24 100 $\mu$ s to 700 $\mu$ s are effective in removing hard tissue  
25 but preferably within the range 200 to 500 $\mu$ s. These  
26 parameters have to be offered in a group or burst of  
27 pulses. This burst provides clean removal of tissue  
28 at a significant rate given that the pulse separation  
29 is between 200 and 1000 $\mu$ s but is preferably between 250  
30 and 600 $\mu$ s and most preferably 250 to 350 $\mu$ s. The  
31 preferable number of pulses within a burst lies between  
32 1 and 10 most preferably between 1 and 5 for enamel  
33 removal and 2 and 10 for dentine removal.

34

35 The repetition rate of the bursts is within a range  
36 between 100hz and 0, preferably between 75hz and 10hz

1 and most preferably 50hz to 30hz.

2  
3 This mode of operation of a CO<sub>2</sub> laser provides a  
4 materially different interaction to that achieved with  
5 a standard superpulse system (typically 600μs pulse  
6 durations at 500Hz rep rate). That the use of the  
7 combination of parameters described above enables a low  
8 power nominally cw CO<sub>2</sub> laser to drill enamel and that  
9 this is non-obvious in the light of accepted current  
10 perceptions. It has been noted that CO<sub>2</sub> laser  
11 operation of 9.6μm may be beneficial in the removal of  
12 hard tissue because of an enhanced absorption at that  
13 wavelength in hydroxyapatite, the principal inorganic  
14 matrix of enamel. Fowler, B.O. et al Arch. Oral.  
15 Biol. 1966; 11:477-492 infrared spectra of  
16 hydroxyapatites... Fowler, B.O. Inorganic Chem. 1973;  
17 13:207 infrared studies of apatites. A laser operating  
18 at 9.6μm in a mode within the range of parameters  
19 described in this application may be effective.

20  
21 The benefits of a system according to this application  
22 are in the provision of a lower cost laser drill and  
23 one which may be also configured to operate cw or  
24 superpulsed, within the same unit, to provide the well  
25 proved ability of CO<sub>2</sub> lasers to effectively cut soft  
26 tissue.

#### 27 28 Example

29  
30 The pulse shape, grouping and frequency is controlled  
31 by electronic drives to the laser power supply. One  
32 embodiment of the system including laser head power  
33 supply and electronic controls is shown in figure 1.  
34 The main console 1 contains these components and a  
35 particular form of scanning arrangement, 4. The beam  
36 is conducted to the handpiece 3 which includes the

1 water spray nozzle, via the articulated arm 2. The  
2 arm contains lensing such that the beam scanning  
3 pattern produced by the arrangement 4 in the console 1  
4 is reproduced at the handpiece tip. Figure 2 shows  
5 one particular form of the scanning arrangement. The  
6 beam is conducted via deflectors 3, 4 and 5 to the  
7 articulated arm. In doing so the beam passes through  
8 the lens assembly 2 which is caused to rotate by  
9 gearing and a belt to stepper motor 1. If the  
10 rotational axis of the lens are not coincidental with  
11 the beam axis then the focal point describes a circle.  
12 The diameter of the circle may be adjusted by altering  
13 the amount by which the lens optic axis is displaced  
14 from the rotational and beam axis. (Other forms of  
15 scanning arrangements could be adopted including the  
16 use of vibrating mirrors and the scanning could take  
17 place elsewhere in the system, for example near the  
18 handpiece). A visible indicator beam is provided by a  
19 diode laser (7) combined coaxially with the invisible  
20 CO<sub>2</sub> laser beam using the combining optic (6).

21  
22 A CO<sub>2</sub> laser drill operating at  $\lambda = 10.6\mu\text{m}$  delivers 250 $\mu\text{s}$   
23 pulses with the number of pulses in a burst being  
24 selected by the user being between 1 and 8. The gap  
25 between pulses in a burst is 350 $\mu\text{s}$  with a burst  
26 frequency of 40Hz. In use for dental drilling 3 pulses  
27 per burst is recommended for drilling enamel, 7 for  
28 dentine or caries and 1 for clean up.

29  
30 In summary the tailoring of the output of a CO<sub>2</sub> laser to  
31 provide groups of pulses having overall parameters  
32 within the bands specified above in a scanned tightly  
33 focused beam provides effective carbon free drilling of  
34 teeth.

35  
36 The embodiment described above offers advantages in

1 terms of simplicity and cost over existing systems.  
2 In addition it offers significant clinical advantages  
3 in that, whilst set to provide typically encountered  
4 drill hole requirements, resetting to allow finer holes  
5 or cuts can be readily achieved through control of the  
6 scanner. Such fine cuts may find application in other  
7 disciplines and procedures for example in carrying out  
8 surgery on the microbones on the ear. A further  
9 advantage is that, in the same system, by returning to  
10 the conventional mode of operating the laser, the  
11 system can then be used for soft tissue surgery.  
12

13 By changing the size of the scanned pattern a further  
14 application of the tailored pulse grouping would be to  
15 the fine surface ablation of epidermis as required in  
16 the procedure known as laser dermabrasion.  
17  
18  
19  
20  
21  
22  
23  
24

1     Claims

2

3     1.    A a CO<sub>2</sub> laser system for ablation of tissue  
4           comprising a laser head, and control means whereby  
5           a focused laser beam is produced in organised  
6           bursts of pulses from the laser head to an area of  
7           tissue to be ablated.

8

9     2.    A system as claimed in Claim 1 comprising scanning  
10           means by which the focused beam traverses a  
11           defined area such as an area of tissue to be  
12           ablated.

13

14    3.    A method for the controlled ablation of tissue  
15           comprising the steps of delivering a focused laser  
16           beam from a CO<sub>2</sub> laser in organised bursts of pulses  
17           to the tissue to be ablated.

18

19    4.    A method as claimed in Claim 3 comprising a step  
20           whereby the focused laser beam scans the area to  
21           be ablated.

22

23    5.    A method as claimed in Claim 3 or 4 wherein the  
24           wavelength ( $\lambda$ ) of the laser pulses is between 9  
25           and 11 $\mu$ m.

26

27    6.    A method as claimed in any of Claims 3 to 5  
28           wherein pulse duration is between 100-700 $\mu$ s.

29

30    7.    A method as claimed in any of Claims 3 to 5  
31           wherein a burst comprises between 1 and 10 pulses.

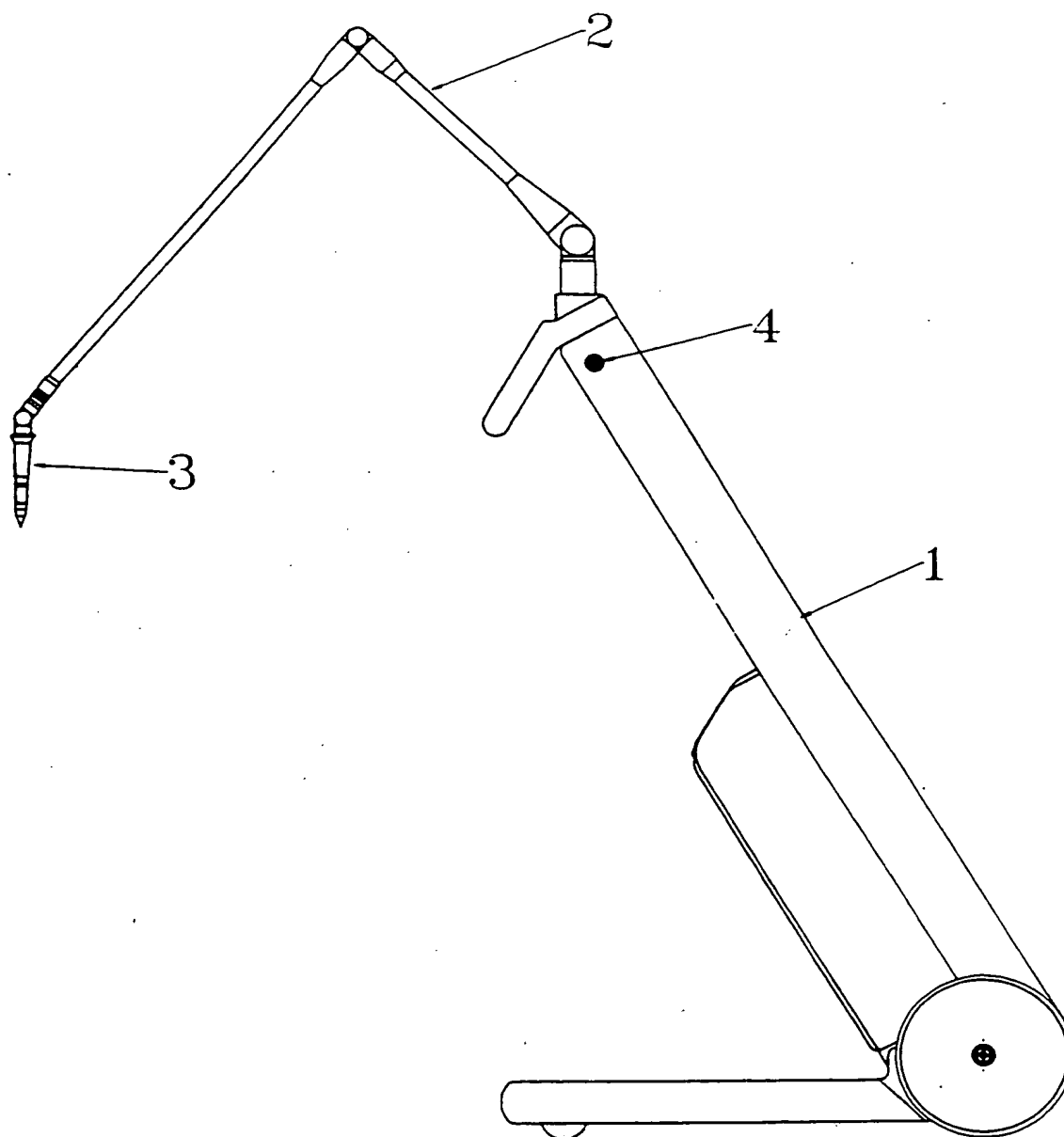
32

33    8.    A method as claimed in any of Claims 3 to 7  
34           wherein the pulse in a burst are separated by  
35           between 200 and 1000 $\mu$ sec.

36

- 1     9.    A method as claimed in any of Claims 3 to 8  
2        wherein pulse separation is between 25 and 600 $\mu$ s,  
3        250-350 $\mu$ s.  
4
- 5     10.   A method as claimed in any of Claims 3 to 9  
6        wherein pulse separation is between 250-350  $\mu$ s.  
7
- 8     11.   A method as claimed in any of Claims 3 to 10  
9        wherein burst repeat frequency may be between 10  
10       and 100Hz.  
11
- 12    12.   A method as claimed in any of Claims 3 to 11  
13       wherein burst frequency is between 30-50 Hz.  
14
- 15    13.   A method as claimed in any of Claims 3 to 12  
16       wherein 10 to 50mJ of pulse energy is delivered in  
17       a beam focused to a diameter of typically 300 $\mu$ m.  
18  
19

1 / 2

FIGURE 1

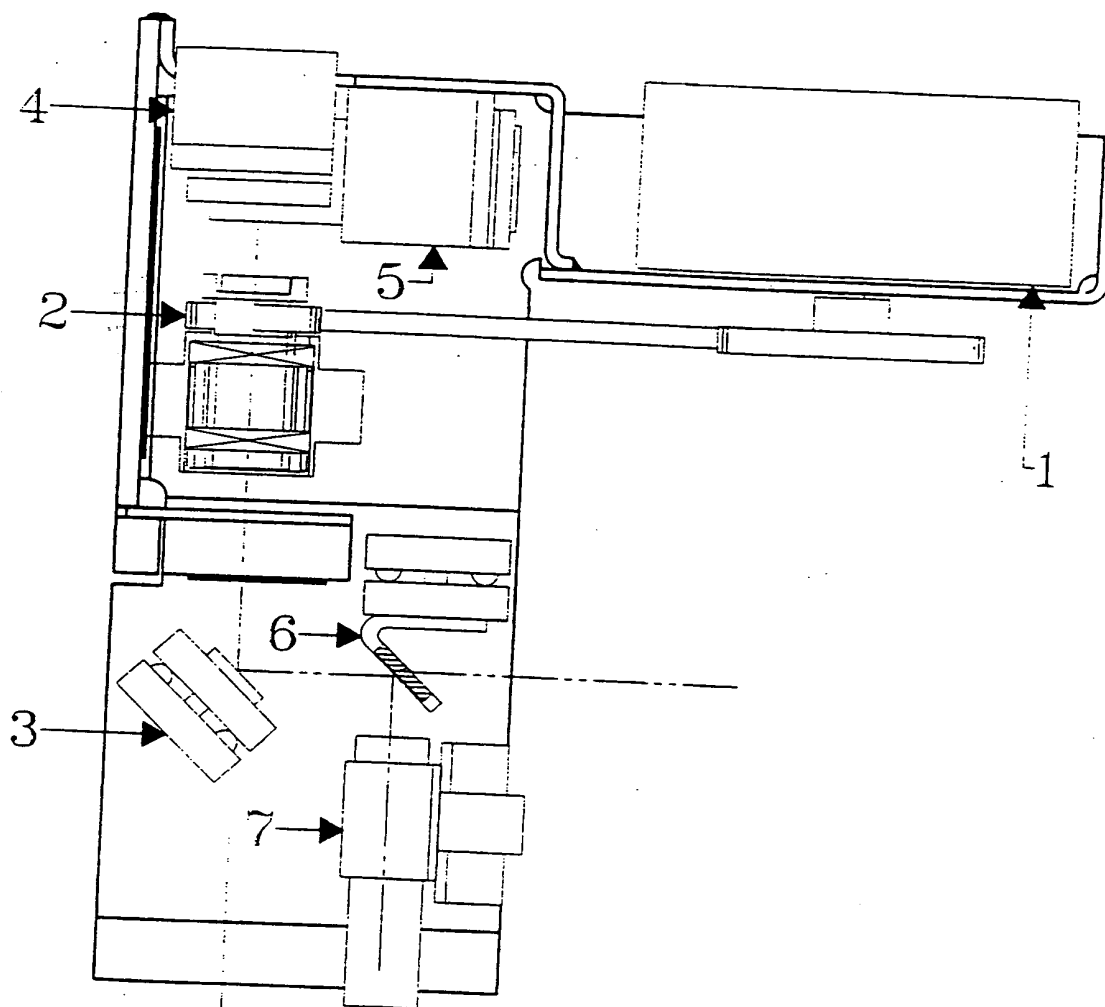


FIGURE 2



## INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 96/01002

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 A61B17/36 A61C1/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 A61B A61C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US,A,4 638 800 (MICHEL) 27 January 1987 see column 5, line 65 - column 6, line 3 see column 14, line 12 - line 16 see column 18, line 36 - line 47 ---	1,2
Y	WO,A,94 26203 (PATEL) 24 November 1994 see page 12, line 31 - page 13, line 7; claims 2,4 ---	1,2
A	EP,A,0 256 671 (NOBLE) 24 February 1988 see page 5, line 6 - line 9 see page 8, line 15 - page 9, line 8 ---	1
A	US,A,5 207 671 (FRANKEN ET AL.) 4 May 1993 see claims 1,2 ---	1
A	US,A,5 321 715 (TROST) 14 June 1994 see claims 10,21 -----	1

☐ Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

## \* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
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- "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

9 September 1996

Date of mailing of the international search report

16.09.96

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax (+31-70) 340-3016

Authorized officer

Glas, J

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/GB96/01002

**Box I** Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.: 3-13  
because they relate to subject matter not required to be searched by this Authority, namely:  
PCT Rule 39.1(iv) Method.....surgery
2. ☐ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box II** Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 96/01002

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-4638800	27-01-87	NONE	
-----	-----	-----	-----
WO-A-9426203	24-11-94	EP-A- 0696905	21-02-96
		GB-A- 2279569	11-01-95
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